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OPTIMIZATION FOR MAXIMUM PRODUCTION OF TRUCK/SHOVEL MINING SYSTEMS

V. Srajer, N.J. Stuart, R. Kolada, J. Szymanski

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OPTIMIZATION FOR MAXIMUM PRODUCTION

OF TRUCK/SHOVEL MINING SYSTEMS

by

V. Srajer*, N.J. Stuart**, R. Kolada**, J. Szymanski**.

ABSTRACT

Several optimization approaches used by Canadian mining industry were used to investigate surface coal mining operations in Canada. A computer program was applied to optimize truck/shovel system and for various analysis. The analysis of eight western Canadian coal mines included investigation of fleet imbalance, under- and over trucking, development of the criteria for automated truck control, comparison study of various haulers and loaders, haulage layout, driving conditions, machine performance, servicing and maintenance policies, etc.

Each property investigated supplied background information for the study and cooperated in optimization studies. The truck/shovel system optimization study is demonstrated as a test case to outline procedures and step-by-step instruction for similar applications.

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* Head, Operations Research, CANMET, SML, Devon, Alberta

** Research Scientist, Operations Research, CANMET, SML, Devon, Alberta

OPTIMISATION EN VUE D'UN RENDEMENT MAXIMUM DES EXPLOITATIONS MINIÈRES EMPLOYANT DES SYSTÈMES DE CAMIONS/PELLETEUSES MÉCANIQUES

par

V. Srajer*, N.J. Stuart**, R. Kolada, J. Szymanski**.

RÉSUMÉ

On a fait appel à plusieurs procédés d'optimisation employés par l'industrie minière canadienne pour scruter le rendement des mines de charbon à ciel ouvert au Canada. On a appliqué un programme informatique pour optimiser le système basé sur l'emploi de camions/pelleteuses mécaniques, et pour réaliser diverses analyses. L'analyse de huit mines de charbon de l'ouest du Canada comprenait l'examen des déséquilibres du parc de camions, de la sous-exploitation et de la surexploitation du camionnage, l'élaboration de critères sur la commande automatisée des camions, l'étude comparative de divers rouleurs et dragues chargeuses, l'aménagement du roulage, les conditions de roulage, la performance des machines, l'entretien et les politiques d'entretien du matériel, etc.

Chaque propriété a examiné l'information de base fournie aux fins de l'étude, et coopéré aux études d'optimisation. On présente l'étude d'optimisation du système camions/pelleteuses comme cas expérimental permettant d'exposer de façon générale les procédés et la marche à suivre dans le cas d'applications similaires.

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* Chef, Recherche opérationnelle, CANMET, LSM, Devon, Alberta

** Chercheur scientifique, Recherche opérationnelle, CANMET, LSM, Devon, Alberta

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INTRODUCTION

Several of the major factors affecting the productivity of loading and hauling operations were analyzed by computer simulation. Data used in the simulations were collected from selected coal mines in western Canadian coalfields. The findings apply with some limitations to other mines operating under similar conditions.

It is understand that the truck and loader operation represents the bulk of invested capital and the majority of mine operating cost. Profitability at these mines is therefore critically related to the efficiency of the loading and hauling operation. In this optimization study, an analysis of critical factors was performed and the results presented in a form allowing assessment of the importance of each factor on overall productivity.

In the first part of the evaluation, productivity factors are examined. These factors are related to the use of the equipment, shovel and truck productivity, drilling and blasting practices, and system match. The second part of the evaluation is based on data calculated using computer simulations of truck/shovel operation. It establishes criteria for designing for maximum production, using variances in mine design, haulage/ramp gradient, effect of rolling resistance, loading conditions, length of effective shift, and loading/hauling equipment interaction. In the last part of the paper the truck management systems are introduced. A proposal for a total truck/shovel management system and optimization program including expert system software concludes the paper.

PRODUCTIVITY FACTORS

General

The efficient use of mining equipment is determined by its utilization, mine management policies, and assignment of the equipment. Total equipment operating time can be subdivided into two parts, a producing period and an idle period. It is normal that the potential for maintaining truck productivity decrease with their number in the system because of interactions and delays. The degree of activity of shovels or other loading equipment increase with the maximum number of trucks in the system. It is evident that these opposite reactions lead to optimal conditions of operation in specific circumstances.

The operational efficiencies of the loading and hauling equipment at studied mines were examined. Variables studied were number of loading points, hauling units, hauling distances, material loaded, road conditions, and ratio of operating and delay times.

The cost of the operation, capital and operating, was not part of the investigation, because the data was not available for scrutiny or publication outside the mine site. It was also assumed, that no other equipment will be made available to improve production, and therefore the optimization was performed using existing resources. The optimization was for the conditions as existed during the field investigation. The hauling, loading and dumping points were fixed for the purposes of the study.

Loading Equipment Productivity Factors

Apart from digging conditions and fixed delays, there are only a limited number of variables controlling the productive rate of a shovel. The five main factors are:

1. Cycle time,
2. Dipper fill factor,
3. Truck spotting time,
4. Truck allocation, and
5. Variable delays.

Using data collected in the field, these factors were evaluated for each mine separately. Shovel cycle times at mines were surveyed and summarized. The theoretical number of cycles per hour was calculated for each loading equipment type and mining company, providing that data was available. The theoretical quantities per hour were then compared with budgeted quantities for each equipment as supplied by the mines. Spare capacity of each equipment was then calculated. The spare capacity (in %) shows the limit of possible increase in production, if equipment was employed continuously. This value may be reduced by other factors, such as actual operating time and other delays (meal times, shift changes, etc). The other delays will be included later in the evaluation.

The spare production capacity was then summarized in Table 1 for each mine separately. The spare capacity values are given in [bm^3/h]. This spare production capacity may be added to the existing production of these mines, when equipment is working continuously, without stoppages. The values are not calculated for Mines No. 4, 6, and 8, because these mines did not provide quantities of the material for each loading equipment separately, but by pits or as summary values.

Table 1 Spare Production Capacities

Mine	Production capacity		Increase
	Spare	Budget	
	(bm^3/h)	(bm^3/h)	(%)
Mine 1	11,589	11,242	103.1
Mine 2	9,864	5,945	165.9
Mine 3	11,062	6,070	182.2
Mine 5	1,889	3,620	52.2
Mine 7	2,703	3,840	70.4

The shovel or loader cycle times were measured in the field during winter and summer months in 1984 and 1985. These measurements are averages for loading both coal and waste. It may be expected that the cycle times are shorter when loading blasted or ripped coal, but the differences during field measurement were not significant. Several loading equipment manufacturing companies list their cycle times range for easy to hard digging material, with a spread of on average 30 to 35 % for 90 degree turn of the shovel. These values may be used to find the range in production capacities

for investigated mines. However, the spare production capacity in each studied mine is so large that any other detailed investigation will be an exercise in number crunching only.

The utility of the shovel cycle time and the productivity obtained by the shovel is directly proportional to the dipper fill factor. Table 2 was developed by summarizing values of bucket fill factors provided by mining companies and comparing them with budgeted values.

Table 2 Production Potential by Increasing Bucket Fill

Mine	<BQNTPH>	<PPIBF>	<% OF MINE PROD.>
Mine 1	11,242	1,888	16.8
Mine 2	5,945	1,002	16.8
Mine 3	6,070	1,181	19.4
Mine 5	3,620	362	10.0
Mine 7	3,840	526	13.7

NOTE: BQNTPH...budgeted quantities/hour,
PPIBF....potential of production increase.

The truck spotting time is defined as the time taken to correctly position a truck for loading. It depends primarily on the loading method. The drive-by loading technique, often used by tractor-trailer type trucks (Mine 5), is the most straight-forvard in terms of positioning the truck. However, some delay here is incurred by the shovel. This can be minimized when the modified drive-by technique is used. This technique allows the shovel dipper to follow the truck and even commence unloading prior to the truck having completely stopped. This technique was widely used at Mine 5. Trucks stopped at the loading point with one bucket full already unloaded in its box. It was observed, that digging, swinging and dumping represent a total of 18.4 sec of the 27.6 sec cycle. It took from 237 sec to 397 sec to load a truck (depending on type). The 18.4 sec. therefore represents 4.63 to 7.76 % time saving. Using coal quantities loaded at the mine, this represents a potential of increased production equal to 6.3 t, to be loaded during the overlap between truck spotting and the loading cycle for all types of trucks at the mine, or 144 to 242 t/h increased production, depending on truck used.

The double back-up technique can offer no delay to the shovel if an empty truck returns to the shovel prior to the completion of the loading cycle for the first truck. To facilitate truck spotting without using the shovel dipper as a target, some operations use a loading supervisor to direct trucks at the loading site. On average, 115 sec were needed for a loaded truck to pull out from the loading position and have an empty truck back in to the space to be loaded. This survey was taken at Mines 1, 3, and 7 for Unit Rig M-200, Euclid R-170 and Wabco 170 trucks. The time for positioning were quite uniform at all mines and are expected to represent the average at all mines surveyed. This delay may be reduced by the time the shovel needs to dig and fill the bucket and swing time. In average, 15 seconds are needed for this event, therefore 100 seconds may be considered delay time because of single loading. At all surveyed mines, except Mine 5, where drive-by loading is practiced, this represents a delay of 2.13 to 3.85 cycles per

hour, and consequently creates production loss. This loss time is equal to 2.8 % and for each mine production per hour of operation in [bm^3] is:

Mine 1	315
Mine 2	166
Mine 3	170
Mine 7	107

These values are maximum values only, assuming the mines are not using the double loading technique at all. This is often not the case. It was estimated by mine engineering personnel at these mines that double loading is used whenever practical, and it amount to 70 % of total loading time. Therefore, the above mentioned values may be reduced by 70 % to become more realistic estimates.

Variable shovel delays refer here to all delays other than those that are fixed relative to the operation, such as lunch break, shift change, equipment inspection, etc. While maintenance delays are variable, they are largely uncontrollable, and will, therefore, not be discussed.

Clean-up around the shovels is a common delay. It may be overcome or reduced when the double back-up operating method is employed. In the drive-by systems not only does production stop for clean-up, but the frequency of clean-up is commonly higher because of the spillage occuring on the truck route.

The handling of oversized material may present another delay. When a single back-up method is used, boulders may be placed on the shovel side opposite the loading side and removed by mobile equipment while the shovel is loading. When the double back-up method is used, loading on one side must stop until the boulder is removed. These delay times are not recorded separately at any mine and therefore may not be exactly identified. The equipment utilization values varies from 41 to 70 % at the mines investigated. Usually, the ratio of operating and scheduled hours is used to calculate the equipment utilization. The operating hours are scheduled hours less any mechanical and non-mechanical down time. The equipment utilization values indicate total time the equipment is actually operating. The difference between equipment utilization and mechanical availability is then variable shovel delay time. The production loss in [bm^3/h] for Mines 2, 3, 5 and 7 are summarized in Table 3. The Mine 1 was not included in this calculation, because of a different method of calculating the equipment utilization values that was not compatible with the other mines. The production losses are presented in [bm^3/h] and as a percentage of total production at the mines. Up to 39.9 % of non-mechanical production losses were identified at the mines.

Drilling and Blasting Practices

It is almost impossible to get meaningful estimates showing the actual influence of drilling and blasting practices on mine production. It is especially difficult to find the effects of good blasting as compared with poor blasting. Only detailed study and record of all information in conjunction with accurate blasting control for a relatively long period may provide a reasonable answer. This is possible for a single property. Comparisons between different mines contain so many variables that the effects of the blasting operations alone are difficult to isolate.

Table 3 Total Production Loss

MINE	PRODUCTION LOSS DUE TO:					
	MECHANICAL DELAYS		EQUIPMENT UTILIZATION		NON-MECHANICAL DELAYS	
	bm^3/h	%	bm^3/h	%	bm^3/h	%
Mine 2	1331	11.9	5197	46.6	3866	34.7
Mine 3	2000	23.7	2363	28.0	363	4.3
Mine 5	1125	18.5	2460	40.0	1335	22.0
Mine 7	388	11.3	4027	51.2	3.39	39.9

The overburden material is blasted at several mines studied. This so call initial blasting operation is sometimes sufficient and results in well broken material that is easy loaded. Secondary blasting is sometimes required to break larger formations of rock. This blasting is time consuming, costly and results in considerable lost production. Several Canadian surface coal mines in the prairies require surface blasting only, where flat laying overburden or coal is shattered by blasting to be later ripped or directly loaded by shovels or loaders. This blasting is not required to provide the material fragmentation that may be achieved during actual digging operation. This surface blasting will ease loading of the material only. The mining operation is not affected at all, there is no production delay, drilling is done next to the loading operation, no equipment is removed during actual blasting. It is acknowledged that the total loads per shift may vary in relation to various other factors in addition to drilling and blasting practices, such as shovel size, truck size, haul distance, etc., but combinations of these factors with poor drilling and blasting practices may result in reduced production. As a general guideline used by mines operating in mountain deposits, a factor of 0.3 to 0.5 is used to specify reduction in daily production in poor digging as opposed to good digging.

Lost time due to scheduled blasting at mines investigated is up to 2.1 % of total working time. The following Table 4 summarize delay times due to blasting. It should be noted that some companies have no provision for including blast delay times in their production estimates. This is because

the blasting is scheduled during shift changes, meal breaks, and so on, therefore effectively eliminating any lost time. As seen from the table, the allowance for delay due to blasting may be reduced or eliminated in some cases by scheduling blasting during meal breaks or shift changes. This is true especially at Mine 4, where blasting is scheduled during working hours only. A total of 0.6 % of productive time may be saved. 2.1 % of productive time lost was identified at Mine 6. This is highest of all at the mines investigated, but it can not be reduced within the present mine pit configuration. For safety reasons, all mine equipment and personnel must be moved out of the blast area, thereby creating considerable delay. A similar condition nov exists at Mine 1, where equipment must also be moved from the pre-blast location.

Table 4 Summary of Delay Times due to Blasting

MINE	TIME LOST		FREQUENCY OF BLASTING #/WEEK	NOTE
	MIN/WEEK	% OF TOTAL WORKING TIME		
Mine 1	120	1.9	4	DURING LUNCH BREAK ONLY
Mine 2	NO	ALLOWANCE	2	DURING SHIFT CHANGE ONLY
Mine 3	"	"	N/A	NO REGULAR INTERVAL
Mine 4	40	0.6	N/A	DURING WORKING HOURS ONLY
Mine 5	NO	ALLOWANCE	N/A	"SHATTER" BLASTING AS REQUIRED
Mine 6	135	2.1	5	DURING SHIFT CHANGE IF POSSIBLE
Mine 7	NO	ALLOWANCE	3	DURING AFTERNOON BREAK ONLY
Mine 8	58	<1.0	2	DURING SHIFT CHANGE ONLY

Truck Productivity Factors

The relative capacities of the shovel and truck together influence the truck loading time. The longer the loading time the relatively lover the productivity for trucks of equivalent capacity. The drilling and blasting results also affect loading time. The length of haulage and resistance of the roadbed all significantly affect truck productivity. It is understood that increase in the size and number of haulage units corresponds with increases in the number of truck accidents. A maximum operating speed is imposed for all trucks at the mines, effectively limiting production increases. In the Province of British Columbia, maximum operating speed at the mines, the use of emergency run-off lanes and testing for all open pit haulage trucks, are regulated under the provincial statutes. Speed of the slowest truck in the fleet tends to reduce the overall travel speed of the trucks, especialy if "no overtaking" is company policy. This rule applies to all mines investigated. Some mines reduce the delays in the truck cycle by giving haulage trucks priority at all road intersections. Driver skill and its effect on productivity is very hard to quantitatively define. Climate certainly affects mine productivity, however, the effect of bad weather may

be reduced by proper road maintenance, drainage and dewatering practices, immediate attention to dust or snow and ice on the road, and so on.

Road design is one of the most important factors that influences mine productivity. Well designed road systems with provisions for future expansion or alteration, is the main prerequisite for effective management of the mine production. Location of fueling and maintenance facilities will also affect mine productivity. A service bay with a rapid pressure fueling nozzle reduces fueling time considerably. The truck age will not necessarily reduce production, if the truck is properly maintained and serviced, but good supervision certainly ensures maximum output from the available equipment.

The cost of the maintenance for each type of the truck was not made available for the evaluation. However, it was estimated by mine maintenance personnel that in average 30 % of delays may be attributed to truck tires. The cost of tires increases in relation to the size of the truck. The tire cost is estimated to be a major portion of all truck operating costs and also one of the main reasons for operators not getting suitable reductions in cost per ton that may be expected with increased truck size.

Truck/Shovel System Match

Each mining operation investigated consists of several load-haul-dump systems. These systems can be identified to some extend as independent entities. The production at each entity - at each mining shovel site - is dependent on rock type, quality of material fragmentation and the size and number of trucks arriving to be loaded. The number of loads hauled depends on queuing conditions at the shovel and dump points and the number and speed characteristics of other trucks in the load-haul-dump cycle. The dump points at several mines have limited capacities and are subject to blockages and other delays. Such an operation can not be planned effectively by using average shovel outputs and estimated truck cycle times. The introduction of additional operating trucks to the system will not always increase overall production, it may even congest the system further. An accurate working model of the whole system may establish optimum operating procedures without costly experimentation in the field. It is expected that event-based simulation models should provide the ansver.

Methods of Increasing Truck/Shovel Productivity

The productivity factors and practices were identified. This part of the presentation summarizes some of the methods that may help increase truck/shovel productivity. Topics discussed here are:

- shift change analysis,
- meal breaks analysis,
- truck weighing systems, and
- shovel/truck dispatch system.

Additional delays such as pover outages, traffic and personal delays, weather, are not analysed because they are not significant for analysis of mine productivity, or are unpredictable in nature. These delays may be included in event-based models for long term simulation studies. Some of these delays may be reduced by introduction of advanced sensing and truck locating devices.

Shift Change Analysis. Mining companies allocate some time for mine personnel to travel to and from mine site and to check their equipment as part of their working time. Several provisions were discussed at the mine sites. It was decided not to introduce any changes to this system, because any change will require extensive negotiation between management and labour. All mining companies, excluding Mines 3 and 4, are operating on 12 hour shifts. At several mining companies this change was introduced as a temporary measure for a limited period of time. After expiration of the time, mine management was requested by the labour representatives to keep the 12 hour schedule. The mine management agreed, because some of the shift change delays were reduced. The labour requested this to have more leisure time and because travel times to the mines in western Canada are considerable. The working hours are spread over several weeks in a repeating schedule, so on average, a 40 working hour week is maintained. The shift change practices are summarized in Table 5. It is understand from the table that the Mines 6 and 7 have lovest lost time due to the shift change, only 2.8 %. Mines 3 and 4 have highest amount of lost time. This is because both mines are operating on an 8 hours/shift basis. In average, lost time due to shift change at mines with scheduled 12 hour/shift is 3.73 % of total productive time. It is concluded that by increasing shift time from 8 to 12 hours, lost time will be reduced in average by 2.52 %.

Table 5 Shift Change Analysis

MINE	TIME LOST		NOTE
	HRS - MIN	% OF PRODUCTION TIME	
Mine 1	365 - 00	4.17	15' MACHINE CHECK INCLUDED
Mine 2	473 - 20	5.50	20' BEFORE AND AFTER SHIFT START
Mine 3	531 - 00	6.25	15' FOR MACHINE CHECK
Mine 4	357 - 00	6.25	15' FOR MACHINE CHECK
Mine 5	254 - 00	2.90	20' ALLOWED FOR TRANSPORTATION
Mine 6	157 - 00	2.80	20' ALLOWED FOR TRANSPORTATION
Mine 7	236 - 00	2.80	20' MACHINE CHECK INCLUDED IN MECHANICAL DOWNTIME
Mine 8	354 - 00	4.20	15' MACHINE CHECK INCLUDED

Meal Breaks Analysis. Working hours at the mines investigated include meal breaks. The meal breaks are scheduled 3 or 5 times during the shift. In average, one hour of productive time per shift is lost due to meal breaks. This represents an average 8.31 % of productive time for operations with 12 hour shift, or 10.42 % for operations with 8 hour shift. The difference is 2.11 % in favour of 12 hour shift operation.

A study was performend at the Mine 5 (Srajer, 1985) to identify changes in workers performance during first, middle and last third of the 12 hour shift. The performance slightly decreased in second third of the shift (by

1.3 %) as compared to the first part of the shift, but the last third was 0.7 % higher than first third. It was concluded that the difference was negligible, because overall performance in 12 hour shift operation was higher than in 8 hour operation, due to elimination of meal breaks and shift change delays.

Truck Weighing Systems. Several truck and shovel dipper weighing systems were investigated (Srajer, 1986). The systems range from simple utilization of a series of lights on the exterior of the truck to indicate the status of the load to the shovel operator, to a total truck management system that provides complete monitoring of truck performance. These systems are installed to provide and maintain uniform load to be hauled from loading to dumping points and also to provide reliable data for mine productivity calculation and mine planning.

The OBDAS (On-Board Data Acquisition System) was identified as the one of the advanced systems where data collection will not depend on the truck operator, and was jointly tested with Gregg River Resources Company at their mine property near Hinton in Alberta (Gould, et al, 1988). The system was installed on two Euclid R-170 trucks and tested during the first six months in 1987 under normal operating conditions. The objective of this project was to measure the practical application of the system. The assessment centred on the system ability to pass the following tests:

- provide accurate and useful information,
- function reliably with minimum maintenance, and
- demonstrate reduction in the overall cost of operation.

The OBDAS system consists of four weight sensors, distance sensor, inclinometer, load display system, off-centre alarm, two load/dump sign posts, fuel consumption indicator, and data transmission system. During the trial period the system function was able to:

- minimize operator dependence,
- give reliable data on truck payload, time taken for loading, hauling, dumping, and truck operation such as speed, fuel consumption, gear used,
- communicate the above data in real time to a base station,
- provide both truck and shovel operators with an indication of payload and its distribution, and
- facilitate the reception of data at high speed, buffering the data for downloading in real time to a central computer system.

The Gregg River mine was extremely pleased with the system performance during the trial period. Using their preliminary estimate of the cost saving by using this system (as of January, 1988), it was stated the system may represent $ 240,000 saving annualy, easily justifying the capital expenditure of $ 60,000 (Gould et al, 1988).

Truck/Shovel Dispatch System. The truck/shovel dispatch system is used to dynamically balance the loading/hauling unit distribution, and to optimize production and/or provide blending for the coal preparation plan. The dispatch system may be fully justified by the mining company if it can be proved that the same production output may be achieved with less equipment. This represents a major saving in capital and operating cost. Several mining companies investigated dispatching systems application at their properties.

The general guideline used was to achieve at least 10 % saving in capital and operating cost. This was expected to be achieved by 10 % reduction in equipment requirements. If, for example, a 40 truck haulage fleet was being dispatched, the same production output with four less units could be expected if the fleet had a good dynamic dispatching system. The payback period on the investment is expected to be a matter of months.

DESIGNING FOR MAXIMUM PRODUCTION

The productivity factors were identified and potential for increase in productivity were documented. The developed model of the truck/shovel operation was then used to optimize selected surface coal mining operations. The following limitations were imposed during the optimization process:

1. No additional equipment will become available,
2. Mine design will not be changed, and
3. Operating cost must be reduced.

The examination of the variation in productivity by using the various factors mentioned above was done on a test case. It is expected that the relationship between factors investigated and mine productivity will be relatively similar for other mines. This assumption was tested for two other scenarios of different haulage systems and equipment used and proved to be valid.

Having in mind these restrictions, the model was used to address the following factors:

1. Speed Restriction.

The speed of empty trucks in the test case is restricted to 67 km/h and for loaded trucks to 60 km/h. The maximum speed of 67 km/h was used in the calculation to identify the "base case". The maximum speed was then decreased by 5 % in steps to the speed of 40 km/h and increased by 5 % to 76 km/h. The trucks cycle times, productivities, fuel consumption and TKPH rating were then calculated by running the truck/shovel computer program separately for each change. The calculation is summarized in Table 6.

The TKPH ratio of 926 for each axle was supplied by the Kress manufacture for their truck tires used in the test. This ratio then represents a limiting factor. Under the actual mining conditions the maximum speed is the average speed of loaded and empty trucks and it was assumed to be 63.5 km/h. The TKPH ratio for this speed calculated is then at the limit for the front axle and reaching the limit for the rear axle.

2. Haulage/Ramp Gradient.

The haulage and ramp gradients were designed by mine planners during the mine design stage and any changes or suggestion to change them were out of the scope of this study. An attempt was made, for the sake of illustrating the other possibilities, to reduce or increase haulage gradient in order to find optimum gradient. In the test case, where the terrain is relatively flat, the resulting changes were within 0.5 % of the optimum and only minor changes in productivity were identified. The exercise assumed that no

changes in elevation of loading and dumping points are possible, only reductions in gradients between these points were investigated.

Table 6 Maximum Speed/Productivity

	Speed	Product.	Cycle Time	Fuel Consum.	TKPH	
No	km/h	t/h	min.	l	Axle 1	Axle 2
1	40	234	27.6	43.56	619	683
2	43	299	26.4	46.52	660	729
3	46	310	25.5	45.64	701	774
4	49	320	24.7	49.16	737	814
5	52	327	24.1	49.29	767	847
6	55	334	23.6	49.33	794	877
7	58	340	23.3	49.30	817	902
8	61	344	22.9	49.24	837	924
9	64	349	22.7	49.27	855	944
10	67	352	22.4	49.38	871	962
11	70	356	22.2	49.39	886	978
12	73	359	22.0	49.25	899	993
13	76	361	21.9	49.15	912	1007

3. Rolling Resistance Effect.

The effect of changes to the rolling resistance was assessed by a series of travel time calculations using the test case model. The rolling resistance changes and corresponding increases/decreases in productivity, cycle times, fuel consumption and TKPH values are listed in Table 7. The speed of the truck tested remain restricted to 67 and 60 km/h for empty and loaded trucks respectively. The rolling resistance values were changed by 5 % for each case. The changes were from - 20 to + 20 % from the base case. The base case values were rolling resistance values presently measured at the mine site.

The truck/shovel model assumed that the vehicle speed increases with reduction in rolling resistance values up to the TKPH limiting factor. The TKPH, as shown, will then limit improvement in rolling resistance to 7 % only. Any additional improvement for this type of truck, load and effective working hour, is restricted by the TKPH limiting factor.

It is apparent there is a linear relationship between the change in rolling resistance and change in productivity. It is concluded that for every 5 % improvement in rolling resistance values the production (in t/h) will increase by 1.2 %. During the field studies at Highvale mine in Alberta (Srajer, 1985), a 20 % improvement in rolling resistance was possible by simply scraping excess gravel and packing the road. A 15 % difference in rolling resistance was measured on the same section of ramp in the winter

and summer period. The improvement was due to the frozen surface of the road. Obviously maintenance of the main haulage road may therefore provide exceptional improvement in mine production.

Table 7 Rolling Resistance/Productivity

	R.R.	Product.	Cycle Time	Fuel Consum.	TKPH	
No	%	t/h	min.	l	Axle 1	Axle 2
1	-20	382	21.4	42.39	994	1042
2	-15	364	21.7	44.78	922	1018
3	-10	359	22.0	46.59	901	995
4	- 5	356	22.2	47.89	887	980
5	0	352	22.4	49.38	871	962
6	+ 5	348	22.7	50.96	852	941
7	+10	344	22.9	52.21	836	924
8	+15	340	23.2	53.50	820	906
9	+20	337	23.5	55.90	804	888

4. Loading Conditions.

The loading and hauling conditions may be improved and the corresponding change in production and cycle times calculated. The relationship between loading and hauling conditions on one side and productivity on other was defined and so called nominal conditions specified. The nominal case of the truck/shovel model assumes the following time elements (in min.), that were set up to closely monitor actual mining conditions:

1. Digging and hoisting.....0.200,
2. Manouevering.....0.200,
3. Backing and turning loaded...0.100,
4. Traveling loaded.....0.150,
5. Dumping.....0.080,
6. Backing and turning empty....0.100,
7. Traveling empty.....0.080,
8. Truck exchange.....0.450,
9. Swinging loaded.....0.080,
10. Swinging empty.....0.030, and
11. Site clean-up.....0.500.

The items 8 and 11 (truck exchange, site clean-up) have the longest time values and therefore were investigated. The site clean-up and truck exchange values were varied from their nominal value to zero. The production, cycle times and fuel consumption were calculated. The values calculated by varying the operator efficiency, site clean-up and truck exchange are summarized in Table 8. It is concluded, that 1% improvement in operator efficiency will improve production by 0.30 %, 1 % reduction in site clean-up time will result in 0.045 % improved production, and 1 % reduction in truck exchange time will amount to 0.05 % improved production.

Table 8 Variability in Loading Conditions

Loading Condition Factor	Unit -	Product. t/h	Cycle Time min.	Fuel Consum. l
Operating Efficiency (%)	0.80	315	25.1	56.64
	0.85	321	24.6	56.42
	0.90	326	24.2	56.23
	0.95	332	23.8	56.05
	1.00	337	23.4	55.90
	1.05	341	23.1	55.76
	1.10	345	22.9	55.63
	1.15	349	22.6	55.51
	1.20	353	22.4	55.40
Site Clean Up (Min.)	0.50	352	22.4	49.38
	0.45	353	22.4	49.36
	0.40	354	22.3	49.34
	0.35	355	22.3	49.31
	0.30	356	22.2	49.29
	0	360	21.9	49.16
Truck Exchange (Min.)	0.45	352	22.4	49.38
	0.40	353	22.4	49.36
	0.35	354	22.3	49.34
	0.30	355	22.3	49.31
	0.25	356	22.2	49.29
	0.20	356	22.2	49.27
	0	360	22.0	49.18

In Table 9 the variation in the size of bucket to productivity is summarized. The bucket size was varied +/- 5 % from the standard size of 11.4 m^3, leaving the size of the truck constant. The computer calculated truck fill (based on assumption that truck may be over- or underfill by 5 %) for fully loaded buckets. It is apparent from the table that production for this size of bucket and truck will improve with more than 5 % increase in bucket size. The 5 % increase in size only will result in truck underfill (98.45 %) with no effect on overall productivity. The cycle time will also remain constant for 5, 10, 15 and 20 % increase in the bucket size. By increasing bucket size 10 % in average, the saving of one bucket load is achieved for each truck load and the productivity in [t/h] will improve by 3.55 %.

Table 9 Bucket Size and Truck Payload/Productivity

No	Bucket Size		Truck Fill	Truck Load	No of Buckets	Loading Time	Product.	Cycle Time	TKPH	
	%	m^3	%	t		min.	t/h	min.	Axle 1	Axle 2
1	-20	9.1	103.38	150.9	18	9.41	333	24.4	866	956
2	-15	9.7	104.07	151.9	17	8.94	341	23.9	864	954
3	-10	10.3	104.01	151.9	16	8.47	348	23.5	864	954
4	- 5	10.8	102.24	149.3	15	8.00	350	22.9	868	959
5	0	11.4	100.73	147.1	14	7.53	352	22.4	871	962
6	+ 5	12.0	98.45	143.7	13	7.06	353	21.9	876	968
7	+10	12.5	102.56	149.7	13	7.06	366	22.0	867	958
8	+15	13.1	99.21	144.8	12	6.59	363	21.4	875	966
9	+20	13.7	103.76	151.5	12	6.59	377	21.6	865	955

5. Length of Effective Shift.

The general trend within the mining industry is towards reduced working hours. During the same time, length of the working shift - continuous minimum working period - is increasing. Six mines of eight investigated are working 12 hour shifts. The assignment of the workers is based on an average 40 hour week. This "average" may be achieved over period of several weeks.

The effective working hour for each mining operation investigated was calculated. There are 53.7 effective working minutes per one hour of shift time in the test case. This time was then changed from - 20 % to up to +10 %. The improvement values were alternated by + 1 % to show the actual changes in detail. It is concluded, that for each 1 % improvement in effective working hour the production will increase by 3.53 t/h or by 1.00 %.

The production may also be increased by increasing a number of working days per calendar year. At present, 355 working days per year is considered standard for a continuous mining operation, such as described in the test case. There are 10 statutory holidays per year. By eliminating any one of the statutory holidays, the mine production will increase by 7,000 t/year, a 0.28 % improvement in annual output.

6. Loading / Hauling Equipment Interaction.

Study of the productivity of a loading unit matched with various numbers of trucks requires some method of accounting for the interaction between the loading unit and the associated truck fleet.

The investigation of truck/loader match was performed using the deterministic truck/shovel model. The productivities of each truck cycle were calculated using a single loading shovel. The test run was 12,680 m in length, having 6,325 m long section for loaded trucks and 6,355 m section

for empty trucks. The maximum speed for loaded trucks was 60 km/h, for empty returning trucks 67 km/h.

The production from trucks and shovels were then tested for various cycle times of trucks and travel distances, assuming cycle times of 5, 10, 15, 20, and 25 minutes, in addition to test case time of 22.4 minutes.

The shovel production was calculated for a total of 6 shovels of the same type and capacity. The calculated data are summarized in Table 10.

The following conclusions flow from the truck/shovel productivity match study:

1. Productivity of trucks and shovels are most sensitive to the truck/shovel match when trucks are on short haul routes.
2. It is impossible to obtain maximum productivity from trucks and shovels at the same time.
3. Substantial improvement in productivity can be achieved in the "overtrucked" case by introducing double sided loading, and by improving rolling resistance of the main haulage, increasing speed of haulers up to TKPH value limit, etc.
4. Large capacity trucks are most effective on longer runs and should also be preferably assigned to large shovels.
5. Overtrucking may be recommended for longer runs and large shovels.

Table 10 Productivity of Trucks and Shovels

PRODUCTION OF DUMP TRUCKS (m^3/h)						
Cycle Time / No of trucks	5 min.	10 min.	15 min.	20 min.	25 min.	Test 22.4
1	1364	682	455	341	273	304
2	2727	1364	909	682	545	609
3	4091	2045	1364	1023	818	913
4	5454	2727	1818	1364	1091	1217
5	6818	3409	2273	1704	1364	1522
6	8181	4091	2727	2045	1636	1826
7	9545	4772	3182	2386	1909	2131
8	10908	5454	3636	2727	2182	2435
9	12272	6136	4091	3068	2454	2739
10	13636	6818	4545	3409	2727	3044
11	14999	7500	5000	3750	3000	3348
12	16464	8181	5454	4091	3273	3652
13	17726	8863	5909	4432	3545	3957
14	19090	9545	6363	4772	3818	4261
PRODUCTION OF SHOVELS (M^3/h)						
No. of Shovels	1	2	3	4	5	6
Production	912	1824	2735	3647	4559	5470

TRUCK/SHOVEL MANAGEMENT SYSTEM

The state-of-the-art in computing technology, sensing of equipment, data transfer, and dispatching systems has advanced to the point where there are several truck/shovel optimization models, truck dispatching systems, truck management and data collection systems that may be used in combination with each other or on their own. Several mining companies have implemented dispatching systems with various success. It is understood that the Canadian mining industry is not looking for large and expensive systems to monitor their operation, but rather simple systems that may be installed in stages are preferred. The mining companies are also ready to pool their resources and to develop and test such systems jointly, so the development cost may be shared.

In co-operation with surface coal mining companies in Canada, a project has been proposed to acquire, install, validate, demonstrate and evaluate components of an integrated operating and management system in a producing mine. The following components of the integrated operating and management system are planned to be investigated and tested:

1. Computer based simulation program,
2. Dispatching program,
3. Equipment information system,
4. Data transfer system, and
5. Mobile equipment location devices.
6. Data base system.

The computer based simulation program is intended for short to medium term production scheduling. This program is expected to be developed in several modules that may be used independently. The program will accept real time data generated and collected by various mine site equipment and other information systems and drive the dispatching program.

The dispatching program must dispatch trucks in real time in accordance with a variety of mine site policies. It is proposed that the dispatching system be set up at the beginning of each shift, monitor truck/shovel performance in relation to this basic set-up, and reassign in keeping with specified mine site requirements. This system must allow for user interaction at anytime, and provide trend information as specified by the user.

The equipment information system, with appropriate software, is expected to monitor relevant operating, maintenence and equipment performance data and feed this data for further processing in the simulation and dispatching programs.

The data transfer system could be for example a radio based two way communications system that can send monitored information to a central computer for processing, and relay dispatch decisions as well as provide voice communication. The system must provide temporary on-line storage of data for "on-demand" transmission and further processing.

The mobile equipment location devices will locate and continuously update equipment location using satelite or terrestrial based facilities. This

vehicle location system is defined as an assembly of technologies and equipment that permits centralized and automatic detection and display of the position and movement of equipment through an area. The results of this system component will be integrated into the simulation program that drives the dispatching module.

The data base component is the heart of the system. Format and storage approach must facilitate effective access to the data for a variety of purposes not limited to those included in this technology demonstration program. For example future expansion to include expert system, maintenance and other modules must not demand data base modifications.

A three year co-operative research program is proposed to develop and test the integrated truck management system. This demonstration project will achieve the following:

1. The components of the work (computer simulation program, dispatching, equipment information, data transmission and equipment location) will be integrated into the operating and management system.

2. The system will be installed, validated and operated in a producing mine for the period of at least 12 months.

3. The performance of the system will be evaluated and assessed. This will include as a minimum:
   - the reliability, repeatability, accuracy, and utility of the various system components and outputs,
   - a comparison of the performance, productivity and operating efficiency changes resulting from the introduction of the system,
   - a cost-benefit study of the site specific application of the system,
   - a discussion of the problems and successes associated with the work, and
   - recommendations for improvement to the system.

An integrated operating and management system will be a valuable tool for optimization of surface coal mining operation and improvement of production, safety and profitability of the mining industry. It will advance the knowledge of the processes governing the mining industry and provide means for control of these processes.

CONCLUSION

The major factors affecting the production of the loading and hauling operation were analysed and summarized in this study.

The productivity factors of the truck/shovel operation, namely loading and hauling equipment factors, drilling and blasting practices and truck/shovel system match were examined. The developed truck/shovel deterministic model was used to examine the alternatives. Data from selected mines were evaluated and the following is concluded:

1. Spare production capacities of the investigated mines that may be added to the existing production range from 52.2 % for Mine 5 to 182.2

% for Mine 3. This spare capacity assume continuous production, without stoppages, except due to mechanical delay.

2. The production may be increased by 10.0 to 19.4 % by filling loading equipment bucket to 100 % of the manufacturers suggested capacity.
3. A 2.8 % increase in production may be achieved by eliminating truck spotting times.
4. Up to 39.9 % of non-mechanical production losses were identified at the mines.
5. Lost production time due to scheduled blasting at the mines ranges from 0 to 2.1 % of total working time.
6. Several variables that influence haulage truck productivities were identified and truck/shovel system match was discussed.
7. Four methods of increasing truck/shovel system productivity were identified and discussed. It was concluded, that by increasing shift time from 8 to 12 hours, lost time due to shift change, meal breaks, etc., will be reduced in average by 2.52 %. The truck weighing system installed at the mine may represent an another saving in the truck/shovel operation. A 10 % saving is expected in capital and operating cost alone, if a dispatching system is installed at the mine.

The developed model of the truck/shovel operation was then used to optimize the coal mining operation. The test case mine haulage network was used in this example. The computer model was used to address the following factors:

1. Speed restriction.
   It is concluded that every 3.8 % reduction in maximum speed limitation represents 1 % reduction in production.
2. Haulage/ramp gradient.
   No changes were identified, because of the limitation criteria adopted for the study.
3. Rolling resistance effect.
   For every 5 % improvement in rolling resistance, the production will increase by 1.2 %.
4. Loading conditions.
   A 1 % improvement in operator efficiency will improve production by 0.3 %, 1 % reduction in the site clean-up time will result in 0.045 % improved production, and 1 % reduction in truck exchange time at the shovel will amount to 0.05 % improved production. Each 1 % increase in truck payload when bucket size remains constant, will result in 0.7 % improved production.
5. Length of effective shift.
   For each 1 % improvement in effective working hour the production will increase by 1.00 %.

Co-operative development, demonstration and evaluation of an integrated truck/shovel operating and management system components in a producing Canadian surface coal mine is proposed to advance the knowledge of these systems and to improve performance and operating efficiency of off-highway truck fleet in the mines. This system, which addresses data collection, use of compiled information, and optimization processes for surface mines will provide dynamic real time control of truck/shovel operations.

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